Project	**IEEE 802.16j Relay Task Group**	
Title	**Channel Models and Performance Metrics for IEEE 802.16j Relay Task Group**	
Date Submitted	**2006-05-01**	
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Re:	IEEE P802.16j Relay TG	
Abstract	This contribution proposes the channel models and performance metrics to be used in Relay TG.	
Purpose	Propose the channel models and performance metrics to be used in Relay TG	
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Table of Contents

Channel Models and Performance Metrics for IEEE 802.16j Relay Task Group

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1 Introduction

This contribution proposes the channel models and performance metrics to be used in IEEE 802.16j Relay Task Group for performance evaluation in an urban environment. Models for other environments may be updated in later versions. In addition to typical None Line-Of-Sight (NLOS) channel models found in IEEE 802.16e framework, this contribution also considers Line-Of-Sight (LOS) channel models for the links between base station and relay station, two relay stations and relay station and mobile station. These models are mainly referenced from [1], which specifies the channel models for various relay transmission scenarios.

2 Classification of Propagation Scenarios

The channel models proposed in this contribution are classified by different propagation scenarios, and each of them is defined by LOS or NLOS condition and the type of each hop. The terminologies of BS (Base Station), RS (Relay Station), MS (Mobile Station) and others are based on the definition in IEEE 802.16j contribution C802.16j-06/019 "Definition of terminology used in Mobile Multihop Relay" [6]. We consider both the LOS and NLOS variations for the links in BS↔RS, BS↔MS, RS↔RS, and RS↔MS scenarios. Note that the model for "BS↔MS, LOS" scenario is not considered here due to the fact that the possibility of having LOS condition between BS and MS in urban environment is very low [1]. It should be considered in future contributions with non-urban environment.

2.1 BS ↔ RS, LOS

This scenario is represented by Figure 1, where BS and RS are both deployed above the rooftop and have LOS transmission.

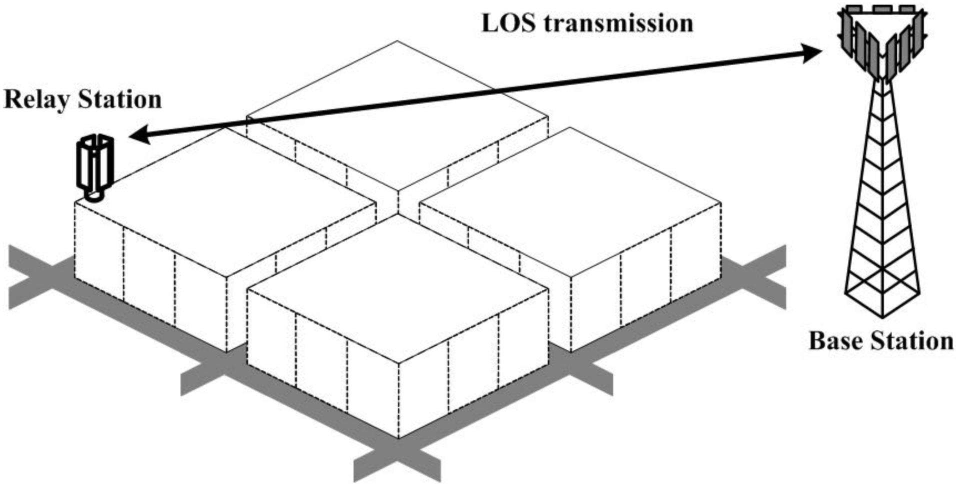

Figure. 1 LOS transmission between BS and RS

2.2 BS ↔ RS, NLOS

This scenario is shown in Figure 2, where BS is deployed above rooftop and RS is below rooftop.

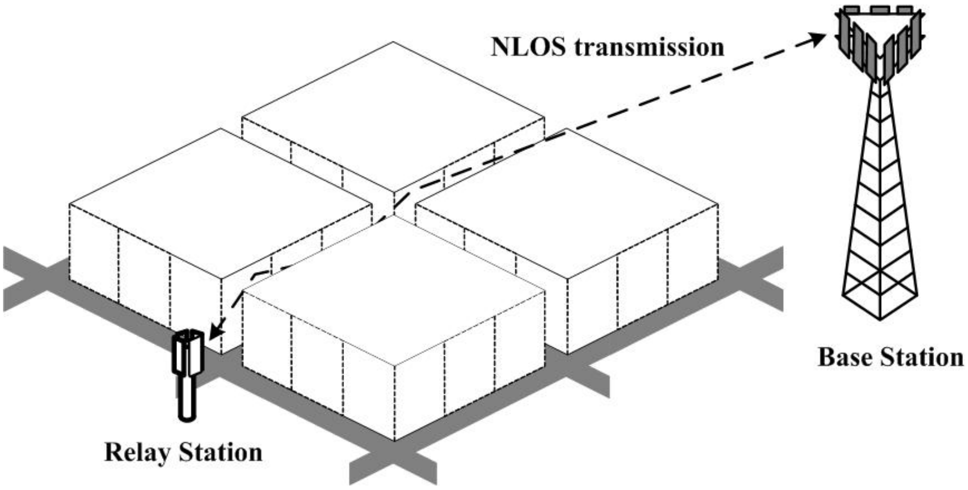

Figure. 2 NLOS transmission between BS and RS

2.3 BS ↔ MS, LOS

This scenario is not considered in urban environment here. The possibility to have LOS condition between BS and MS in urban environment is very low, which is considered as zero in [1]. The interpretation is that the occasional gain from LOS condition in BS↔MS is included in log-normal shadow fading in NLOS environment with corresponding low probability.

2.4 BS ↔ MS, NLOS

This scenario is almost the same as the scenario 2.2 (BS↔RS, NLOS), except the height of MS is different from RS.

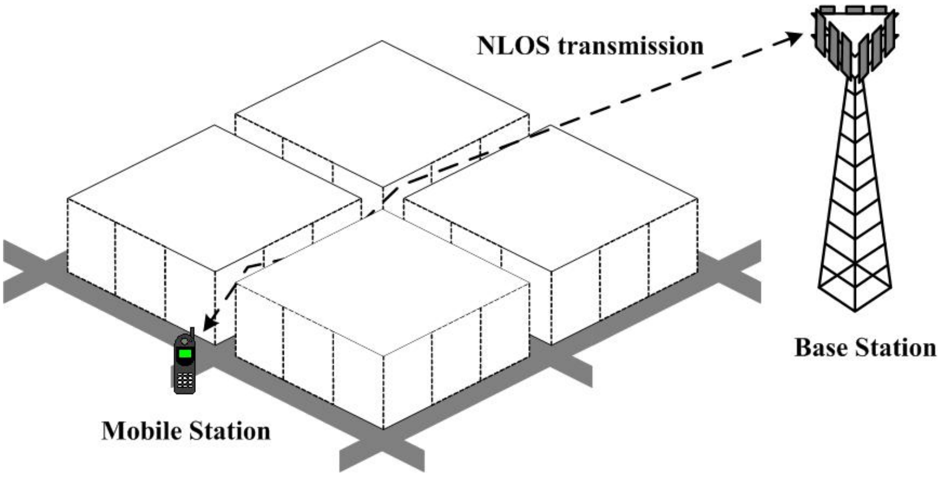

Figure. 3 NLOS transmission between BS and MS

2.5 RS ↔ RS, LOS

This scenario is shown in Figure 4, which is the same as scenario 2.1 (BS↔RS, LOS). Both RSs are deployed above rooftop.

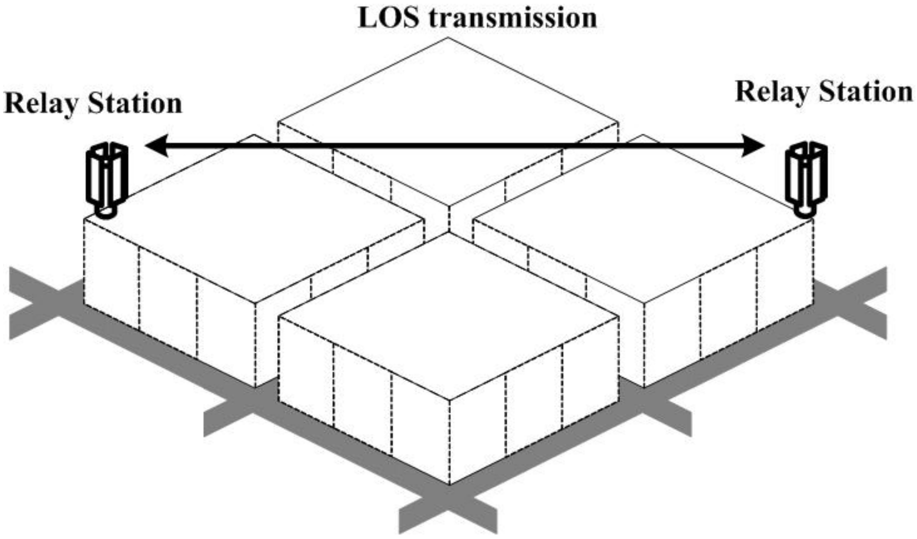

Figure. 4 LOS transmission between RS and RS

2.6 RS ↔ RS, NLOS

This scenario is the same as scenario 2.2 (BS↔RS, NLOS), where one RS is deployed above rooftop and another one is deployed below rooftop. The example is shown in Figure 5.

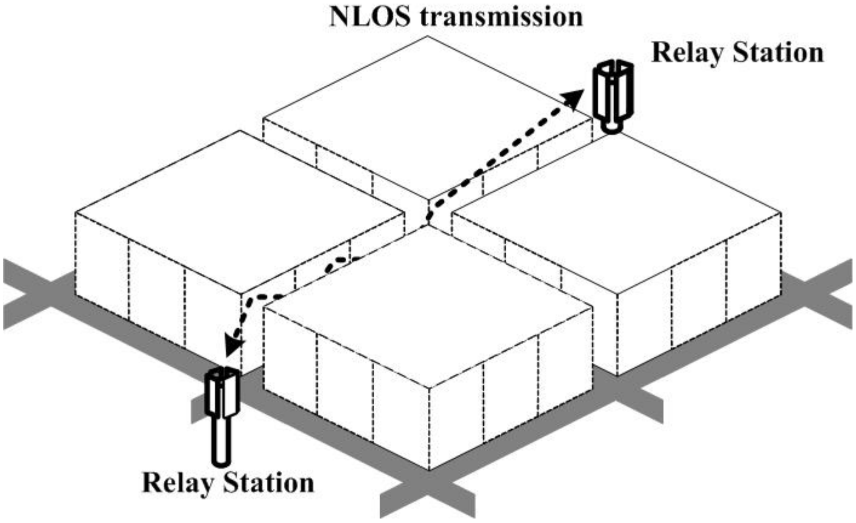

Figure. 5 NLOS transmission between RS and RS

2.7 RS ↔ MS, LOS

This scenario is shown in Figure 6, where the RS is deployed below rooftop and MS height is considered as 1.5m.

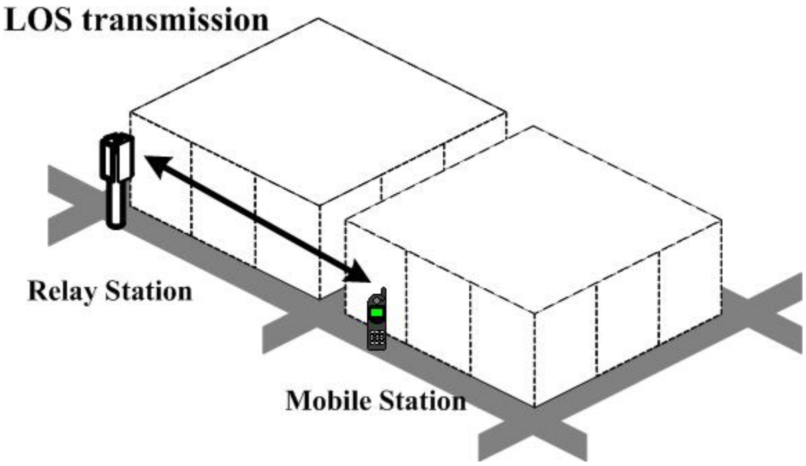

Figure. 6 LOS transmission between RS and MS

2.8 RS ↔ MS, NLOS

This scenario is shown in Figure 7, where the RS is either deployed above or below rooftop and MS height is assumed to be 1.5m.

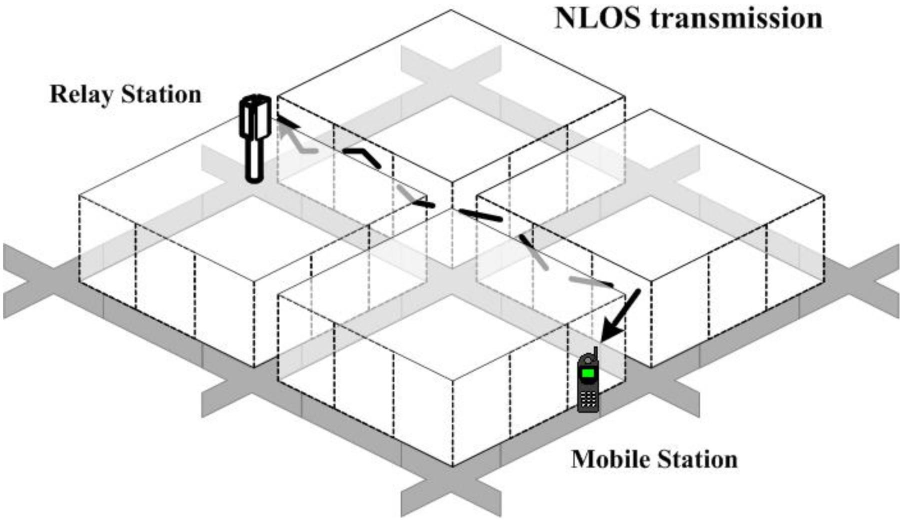

Figure. 7 NLOS transmission between RS and MS

3 Channel Model for each Propagation Scenarios

The channel model for each scenario is characterized by four parts: pathloss, shadow fading, multi-path fading and antenna pattern.

3.1 Pathloss Models

Table. 1 Pathloss Models [1]

Scenario	Pathloss Model	Note
2.1 BS↔RS, LOS 2.5 RS↔RS, LOS	$Pathloss(d)[dB] = 42.5 + 23.5 \cdot \log_{10}(d) + 20 \cdot \log_{10}\left(f_c/5\right)$ *where 30m < d < 8km*	d is the distance in meter between transmitter and receiver f_c is the carrier frequency in GHz Both transmitter and receiver are above rooftop.
2.2 BS↔RS, NLOS 2.4 BS↔MS, NLOS 2.6 RS↔RS, NLOS	$Pathloss(d)[dB] = 38.4 + 35 \cdot \log_{10}(d) + 20 \cdot \log_{10}\left(f_c/5\right) - 0.7 \cdot h_m$ *where 50m < d < 5km*	In scenario 2.2 and 2.4, BS is above rooftop. In scenario 2.6, one RS is above rooftop and another one is below it. h_m is the height (meter) of the RS below rooftop (1.5m~10m) for scenario 2.2 and 2.6. $h_m = 1.5$ for scenario 2.4.
2.7 RS↔MS, LOS	$Pathloss(d)[dB] = 41 + 22.7 \cdot \log_{10}(d) + 20 \cdot \log_{10}\left(f_c/5\right)$ *where 10m < d < 650m*	Both RS and MS are below rooftop.
2.8 RS↔MS, NLOS	$Pathloss(d_1, d_2)[dB] = 65 + 0.096 \cdot d_1 + (28 - 0.024 \cdot d_1) \cdot \log_{10}(d_2) + 20 \cdot \log_{10}\left(f_c/5\right)$ *where 10m < d_1 < 550m and w/2 < d_2 < 450m* *(w is the street width)*	Both RS and MS are below rooftop. d_1 and d_2 are the distances along main street and perpendicular street respectively. (see Figure 8)

Note 1: The parameters of the channel models above assume a certain baseline carrier frequency $f_{baseline}$ (in above table, $f_{baseline}$ is 5GHz). To use the channel model in other carrier frequency f_c, a factor $20 \cdot \log_{10}(f_c/f_{baseline})$ is introduced to represent the pathloss difference in dB.

Note 2: $f_{baseline}$ was originally considered as 2.5GHz for scenario 2.1 and 2.5 in [1]. The $f_{baseline}$ is modified to be 5GHz for the consistency with other pathloss equations.

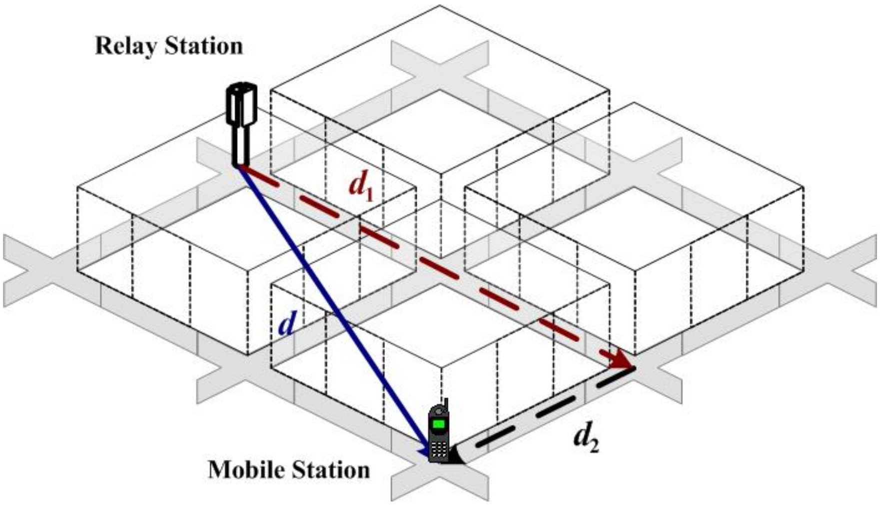

Figure. 8 Street layout for scenario 2.8

3.2 Shadow Fading Model

Log-normal shadow fading model with correlation [2] is considered in this contribution, which has different parameter for each scenario. De-correlation distances associated with shadow fading are of the same order as the size of the objects causing the fading. The de-correlation distance is considered to be 20m [3].

Table. 2 Shadow Fading Parameters [1]

Scenario	2.1 BS↔RS LOS	2.2 BS↔RS NLOS	2.4 BS↔MS NLOS	2.5 RS↔RS LOS	2.6 RS↔RS NLOS	2.7 RS↔MS LOS	2.8 RS↔MS NLOS
Standard deviation of log-normal shadow fading (σ)	**3.4dB**	**8dB**	**8dB**	**3.4dB**	**8dB**	**2.3dB**	**3.1dB**

Informative Note: The shadow fading in LOS scenarios represents the different level of first Fresnel zone clearance.

3.3 Multi-path Fading Models

3.3.1 WINNER Multi-path Fading Model

Multi-path fading is the result of interference between two or more versions of a transmitted signal arriving at a receiver. Due to the nature of electromagnetic (EM) wave propagation, a single transmission from a wireless device will often encounter 'reflective' objects resulting in multiple versions of the transmitted waveform that are attenuated, phase shifted and delayed in time. The clustered delay line model was originally introduced in [1], which means the fading within each tap is generated by sum of sinusoids, i.e. the rays within the cluster of that tap. It composes a number of separate delayed clusters, and each of them has a number of multipath components (rays) that have the same known delay values but differ in angles of departure and arrival. However, we only introduce the corresponding tapped delay line model in this version. The detail parameters and description on cluster delay line model can be found in [1].

The parameters for each propagation scenario are shown in following tables.

Table. 3 Tapped Delay-Line Model for Scenario 2.1 (BS↔RS, LOS) and 2.5 (RS↔RS, LOS)

Tap index	Delay [ns]	Power [dB]	AoD [°]	AoA [°]	K-factor [dB]
1	0	-0.39	0.0	0.0	21.8
2	10	-20.6	0.9	0.2	−∞
3	20	-26.8	0.3	1.5	
4	50	-24.2	-0.3	2.0	
5	90	-15.3	3.9	0.0	
6	95	-20.5	-0.8	3.6	
7	100	-28.0	4.2	-0.7	
8	180	-18.8	-1.0	4.0	
9	205	-21.6	5.5	-2.0	
10	260	-19.9	7.6	-4.1	

Table. 4 Tapped Delay-Line Model for Scenario 2.2 (BS↔RS, NLOS), 2.4 (RS↔MS, NLOS), and 2.6 (RS↔RS, NLOS)

Tap index	Delay [ns]	Power [dB]	AoD [°]	AoA [°]	K-factor [dB]
1	0	-0.5	0	0	−∞
2	5	0.0	4	4	
3	135	-3.4	-3	7	
4	160	-2.8	-4	10	
5	215	-4.6	-7	21	
6	260	-0.9	8	-45	
7	385	-6.7	10	-75	
8	400	-4.5	17	65	
9	530	-9.0	-8	160	
10	540	-7.8	-8	155	
11	650	-7.4	-4	88	
12	670	-8.4	-7	80	
13	720	-11.0	-9	-90	
14	750	-9.0	-9	-105	
15	800	-5.1	12	8	
16	945	-6.7	-17	45	
17	1035	-12.1	19	50	
18	1185	-13.2	12	-15	
19	1390	-13.7	19	-25	
20	1470	-19.8	21	100	

Table. 5 Tapped Delay-Line Model for scenario 2.7 (RS↔MS, LOS)

Tap index	Delay [ns]	Power [dB]	AoD [°]	AoA [°]	K-factor [dB]
1	0	0	0	0	16
2	10	-1.2	-22	-10	9
3	30	-4.4	-12	20	3
4	45	-8.4	-2	-123	−∞
5	65	-13.0	10	-31	
6	85	-15.1	-4	161	
7	105	-16.1	8	-7	

Table. 6 Tapped Delay-Line Model for scenario 2.8 (RS↔MS, NLOS)

Tap index	Delay [ns]	Power [dB]	AoD [°]	AoA [°]	K-factor [dB]
1	0	-1.25	4	0	9
2	10	0	40	25	6
3	40	-0.38	-10	29	−∞
4	60	-0.10	48	-31	
5	85	-0.73	-36	37	
6	110	-0.63	-40	21	
7	135	-1.78	-26	13	
8	165	-4.07	-28	117	
9	190	-5.12	-12	21	
10	220	-6.34	-14	1	
11	245	-7.35	14	15	
12	270	-8.86	8	9	
13	300	-10.1	-24	19	
14	325	-10.5	-14	1	
15	350	-11.3	-22	-13	
16	375	-12.6	2	11	
17	405	-13.9	8	-1	
18	430	-14.1	-2	43	
19	460	-15.3	-10	33	
20	485	-16.3	-54	-19	

3.3.2 Doppler Spectrum

The Doppler spectrum has not been well addressed in [1], therefore, the following approximation is considered in this contribution.

$S(f)=\begin{cases}1-1.72f_0^2+0.785f_0^4 & |f_0|\le 1\\ 0 & |f_0|>1\end{cases}$ where $f_0=\frac{f}{f_M}$ and f_M is the maximum Doppler frequency.

Details on how to implement a Doppler spectrum can be found in Appendix B of [5].

3.4 Channel Coherence Bandwidth and Time

Coherence bandwidth B_C is a statistical measure of the range of frequencies over which the channel can be considered flat, and describes the similarity of the frequency response at different frequencies across this bandwidth. We consider the more relaxed definition of a coherence bandwidth as the frequency range over which the correlation function is above 0.5 and hence $B_C \cong$ 1/ (5×rms worst case delay spread). The worst case RMS delay spread as shown in SUI and ITU channel models above is 20μs and $B_C \cong 10$ *KHz*. This means that for delay spread values up to 20μs, multi-path fading exhibits a flat fading over a 10*KHz* subcarrier bandwidth. This is inline with current 802.16e scalable OFDMA subcarrier frequency spacing of 11.16*KHz*.

Channel coherence time T_C is the time over which the channel may be considered coherent. The definition of coherence time implies that two signals arriving with a time separation greater than T_C are affected differently by the channel. Coherence time and Doppler shift are inversely proportional to each other. The inverse of the channel coherence time T_C is the minimum channel update rate required for proper channel estimation and equalization, which can be calculated [7] in the following Equation:

$$T_C=\frac{9}{16\cdot\pi\cdot f_M}$$

For example, a mobile with maximum speed V of 125km/hr (= 34.72m/s) has a Doppler shift $f_M = V/\lambda$ = 34.72m/s/(3×10^8/3.5GHz) = 34.72/0.0857 = 405Hz. Note that λ is calculated assuming the operating frequency of 3.5GHz. Coherence time is then calculated using above equation to be 0.442ms.

Beside BS, a RS is anticipated to perform channel estimation for the link RS ↔ RS and RS ↔ MS.

3.5 Antenna Pattern

For omni-directional antenna, the antenna gain should be $0\ dBi$ for each direction. For 3-sector or 6-sector antenna, the antenna pattern specified by [4] should be applied:

$$A(\theta)=-\min\left[12\cdot\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]\ dBi$$

where

- $-180^\circ<\theta\le 180^\circ$;
- θ is the angle between the direction of interest and the steering direction of the antenna;
- θ_{3db} = 70^o is the 3 dB beam width for 3 sector antenna, 35^o for 6 sector antenna.
- A_m = 20dB maximum attenuation (front-to-back ratio) for 3 sector antenna, 23dB for 6 sector antenna.

4 Performance Metrics and Presentation

If we all use the same channel models, traffic models, PHY abstraction models, we shall be able to use the generated simulation/analysis results and compare among ourselves to choose the optimal proposal for IEEE 802.16j standard. To facilitate this comparison process, we propose the following:

- Performance metrics which are a group of measurable key performance indicators that can be used to evaluate the system performance at both the MAC and PHY layers
- Presentation of performance metrics that is to evaluate and compare different designs

4.1 Performance Metrics

To evaluate the various MAC and PHY design proposals for Relay, the following performance metrics shall be collected:

- Over the air (OTA) throughput:

  $OTA = \frac{b_{tx}}{T_{sim}}$; where b_{tx} is the total number of transmitted bits and T_{sim} is the simulation time.

- Packet delay: delay between the time a packet enters queue at transmitter and the time it is received successively at the receiver over an 802.16e/j air interface
- Throughput for various QoS classes per BS, per RS, per MS, per connection CID, per TCP connection
- Throughput outage probability: percentage of users with averaged user packet call throughput less than some minimum requirement data rate R_{min}*, for example 32 kbps*
- Packet call throughput: which is the total bits per packet call divided by total packet call duration, specifically

$$\text{Packet Call Throughput} = \frac{1}{K}\sum_{k=1}^{K}\frac{\text{bits in packet call k}}{(t_{end\_k} - t_{arrival\_k})}$$

- Sector throughput: total good bits transmitted from transmitter(s) to receiver(s) per second per sector

  $\text{Sector Throughput} = \frac{b_{rx}}{T_{sim}}$; where b_{rx} is the number of successfully received bits.

- BS Duty Factor (Utilization): percentage of time that the BS is actively transmitting (DL) or receiving (UL)
- RS Duty Factor (Utilization): percentage of time that the RS is actively transmitting (DL) or receiving (MMR Link)
- Delay per packet, per connection, per application (e.g. file transfer time)
  - Fixed Delay: switching, transmission, propagation, etc.
  - Variable Delay: buffering, ARQ retransmission, etc.
- Jitter per application which refers to the delay variation
- Overhead ratio of control signaling to data traffic
- Effective spectral efficiency per sector (or site), normalized by the downlink/uplink ratio of TDD system.

$$\text{Sector Spectral Efficiency (SE)} = \frac{\text{Sector Throughput}}{\text{Total Sector BW} \times \text{\%(DL/UL) Split}}$$

and

$$\text{Site Spectral Efficiency (SE)} = \frac{\text{\# Sectors/Site} \times \text{Sector Throughput}}{\text{Total Site BW} \times \text{\%(DL/UL) Split}}$$

- Fairness among MS/SS and among RS for various scheduling algorithms
    - The scheduler parameter should be chosen such that the following fairness criteria is satisfied

Table. 7 Normalized user packet call throughput fairness criterion

Normalized Throughput w.r.t average user throughput	CDF
0.1	0.1
0.2	0.2
0.5	0.5

- Route discovery/recovery time when evaluating routing algorithms
- Dropped calls due to unsuccessful handover, sleep and idle modes
- Packet loss rate: number of dropped packets/number of packets sent per user. Packet loss rate per distance, per sector, and per site can be calculated from this per user packet loss rate number

Figure 9 illustrates some of the key performance metrics.

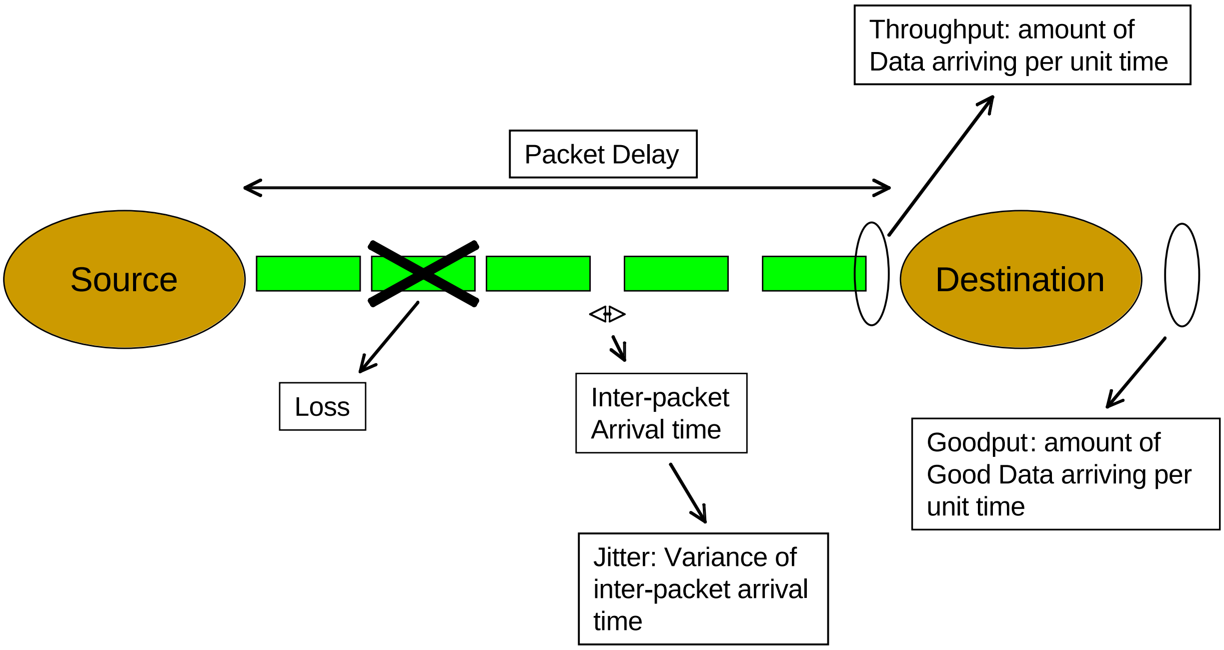

Figure. 9 Key Performance Metrics Illustration

4.2 Presentation of Performance Metrics

Proper interpretation of the collected performance metrics enables ease of understanding. It also allows quick understanding of both the advantages and disadvantages of various proposed designs. Hence, we propose the following metric presentations:

- CDF of user packet delay for delay sensitive traffics (such as VoIP and video streaming)

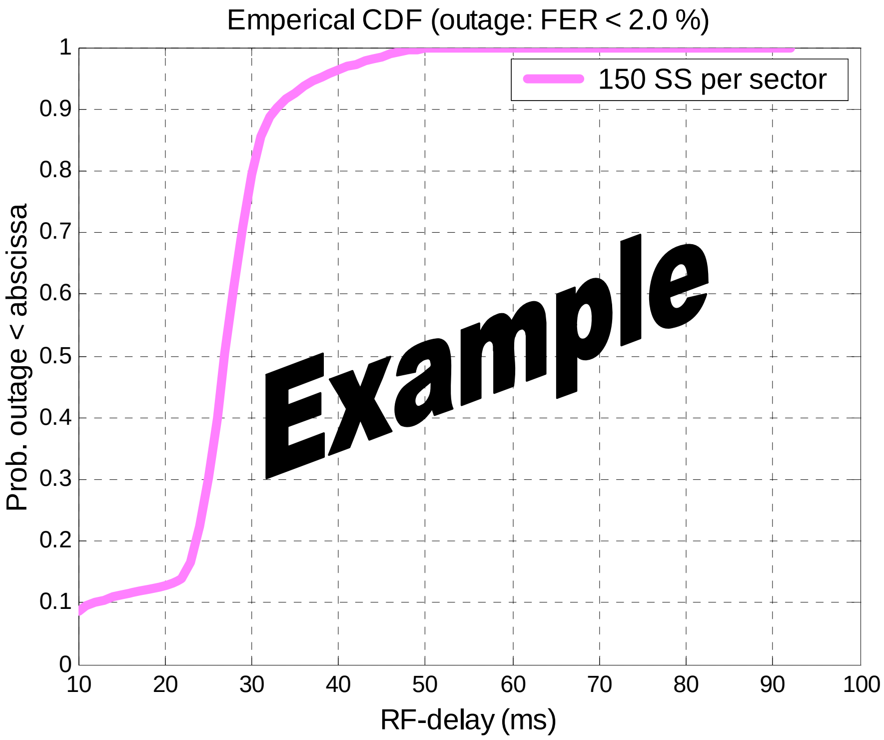

Figure. 10 CDF of user packet delay (Example)

- Plot of system throughput vs. average user throughput

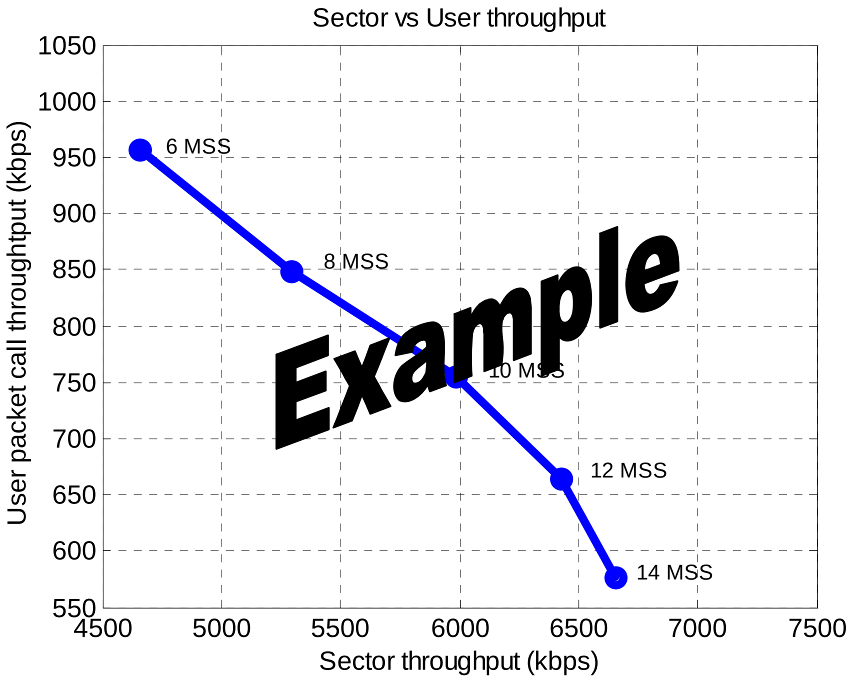

Figure. 11 Sector vs. user throughput (Example)

- CDF of normalized user packet call throughput with fairness criterion

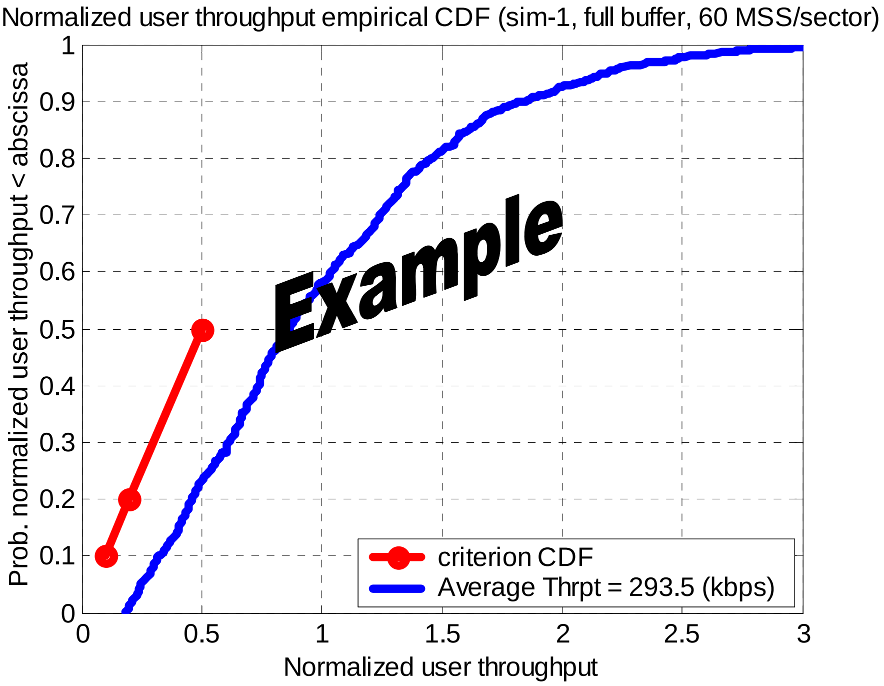

Figure. 12 CDF of normalized user packet call throughput with fairness criterion (Example)

- CDF of user packet call throughput

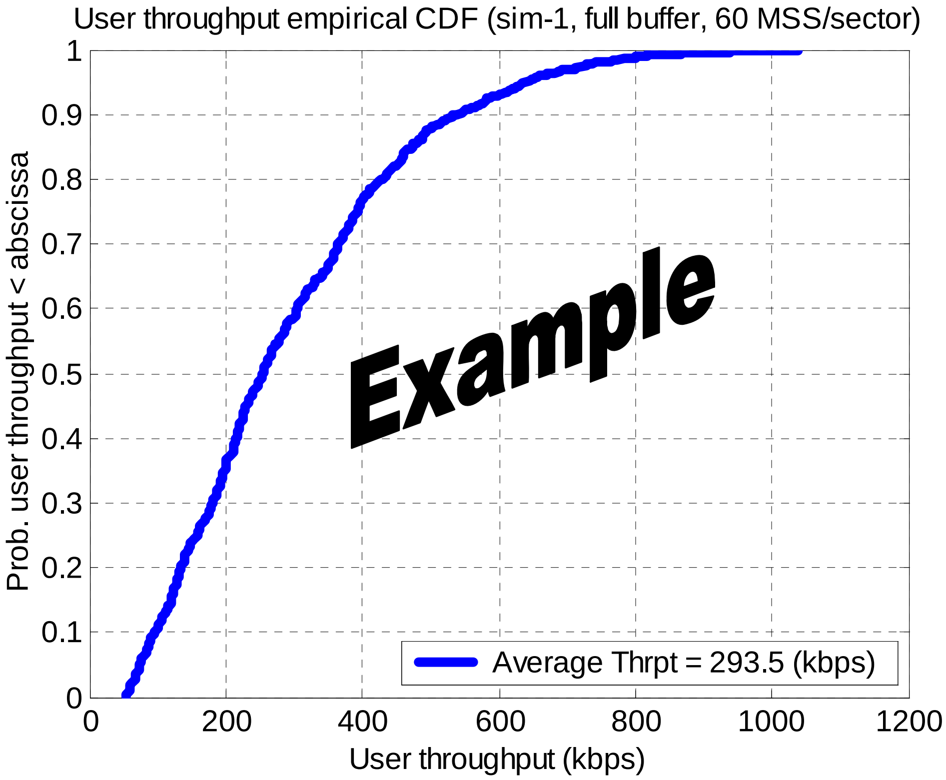

Figure. 13 CDF of user packet call throughput (Example)

- User throughput vs. distance

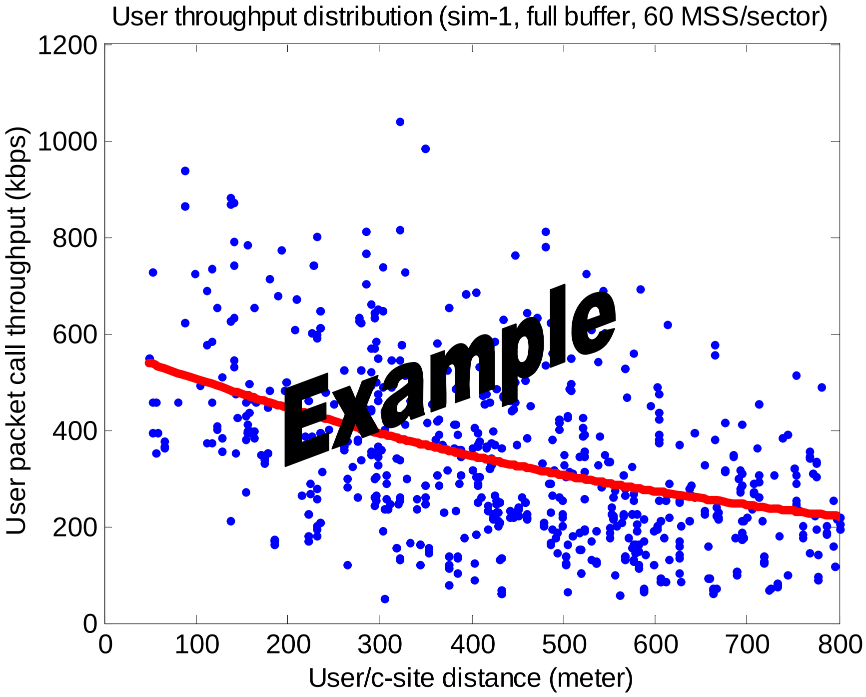

Figure. 14 User throughput vs distance (Example)

- System load vs. Outage probability

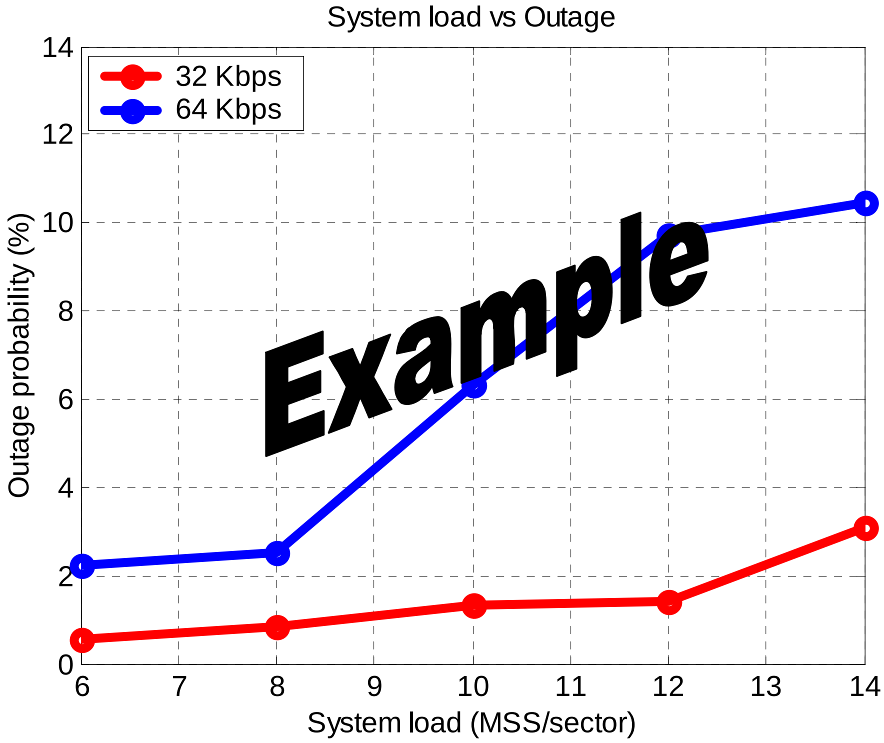

Figure. 15 System load vs. outage (Example)

- CDF of received signal quality

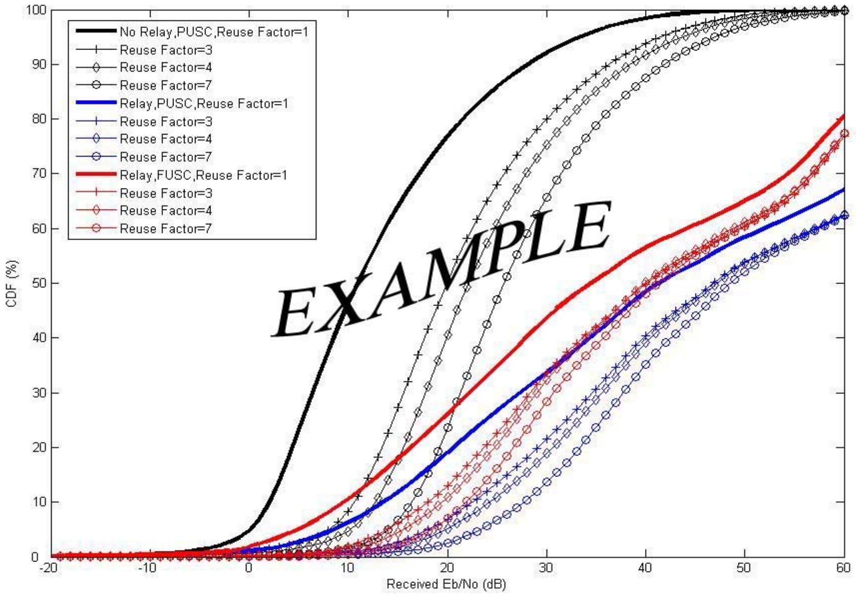

Figure. 16 CDF of received signal quality (Example)

- Effective spectral efficiency

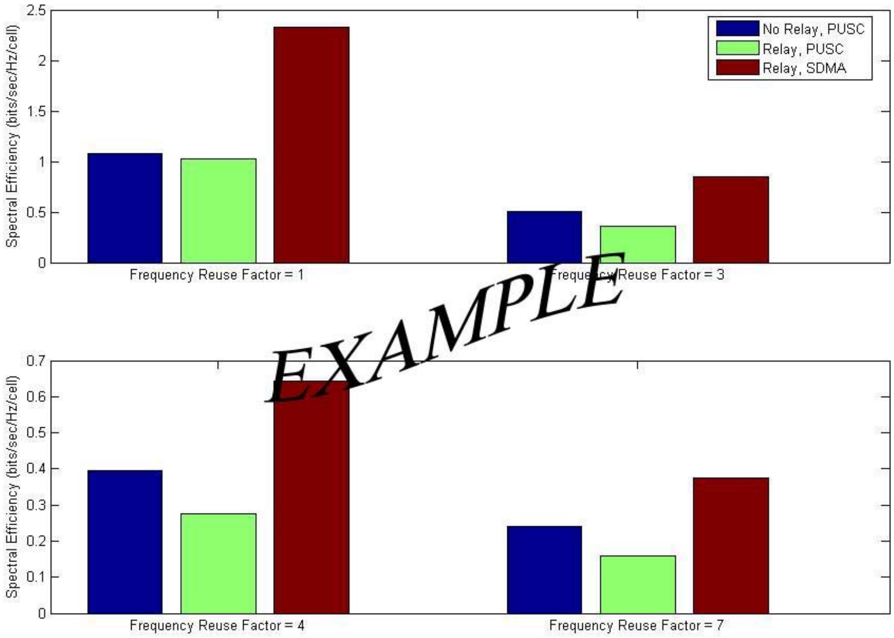

Figure. 17 Effective spectral efficiency (Example)

These presentations will allow one to properly evaluate overall PHY/MAC layer performance in various 802.16j Relay proposals.

5 References

[1] "Final Report on Link Level and System Level Channel Model", IST-2003-507581 WINNER, D5.4 v 1.4, https://www.ist-winner.org/.

[2] M. Gudmundson, "Correlation model for shadow fading in mobile radio systems", *Electronic Letter*, pp.2145-2146, Vol. 27, NO.23, November 1991.

[3] "Universal Mobile Telecommunications System (UMTS); Selection Procedures for the Choice of Radio Transmission Technologies of the UMTS", TR 101 112 V3.2.0(1998-04), UMTS 30.03 version 3.2.0..

[4] 3GPP TR 25.996 V6.1.0, "Spatial channel model for Multiple Input Multiple Output (MIMO) simulations", September 2003.

[5] IEEE 802.16c-01/029r4: "Channel Models for Fixed Wireless Applications", V. Erceg, et al, 2001-07-16, IEEE 802.16 Broadband Wireless Access Working Group http://ieee802.org/16

[6] "Definition of terminology used in Mobile Multihop Relay", IEEE 802.16j MMR Contribution, May, 2006

[7] Rappaport, T.S., "Wireless Communications Principles and Practice", Second Edition 2002, Prentice Hall PTR, Upper Saddle River, NJ.

[8] 3GPP2 C.R1002-0, Version 1.0, "cdma2000 Evaluation Methodology"

6 Revision History

Version No.	Date	Remarks	Author
1.0	5/01/2006	Initial submission for Relay Task Group in Session 43 of IEEE 802.16	David T Chen, I-Kang Fu, Wendy C Wong, Mike Hart

7 Acknowledgements

We would like to acknowledge the following people for their contributions:

- Fan Wang, Asa Masahito, Ikeda Tetsu of Motorola Inc.
- Shilpa Talwar, Hakim Mesiwala of Intel Corp
- Prof. Wern-Ho Sheen of National Chiao Tung University
- Ting-Che Tseng of MediaTek Inc.